National Aeronautics and Space Administration

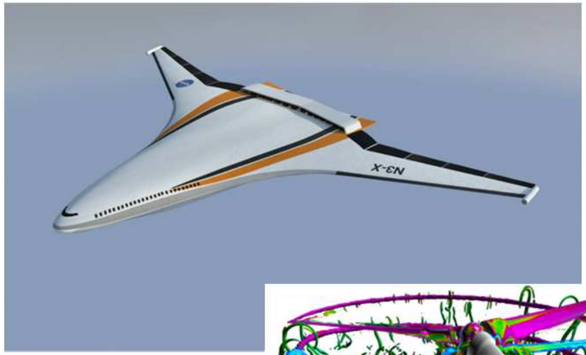
Fundamental Aeronautics Program
Fixed Wing Project
Quiet Performance - Status

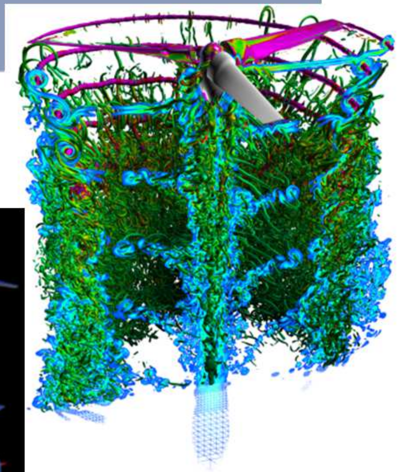
Christopher J. Miller (GRC)
Douglas M. Nark (LaRC)

Acoustics Technical Working Group Meeting
23 April 2013

Fundamental Aeronautics Program

Conduct fundamental research that will generate innovative concepts, tools, technologies and knowledge to enable revolutionary advances for a wide range of air vehicles.



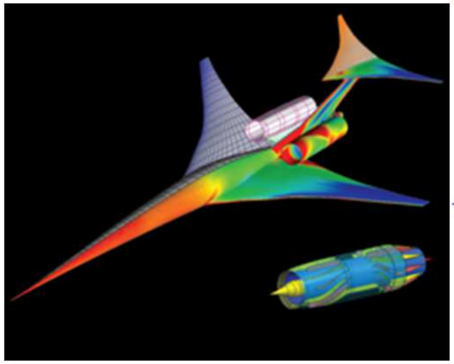


Fixed Wing (FW)

Explore and develop technologies, and concepts for improved energy efficiency and environmental compatibility of fixed wing, subsonic transports.

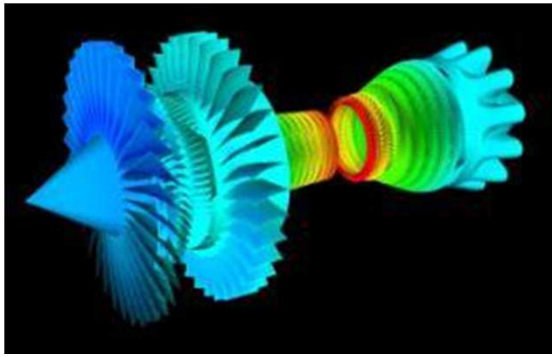
Rotary Wing (RW)

Develop and validate tools, technologies and concepts to overcome key barriers for rotary wing vehicles.



High Speed (HS)

Tool and technology development and validation to address challenges in high speed flight.



Aeronautical Sciences (AS)

Enable fast, efficient design & analysis of advanced aviation systems by developing physics-based tools and methods for cross-cutting technologies.

The Fixed Wing Project

Explore and Develop Technologies and Concepts for Improved Energy Efficiency and Environmental Compatibility for Fixed Wing Subsonic Transports

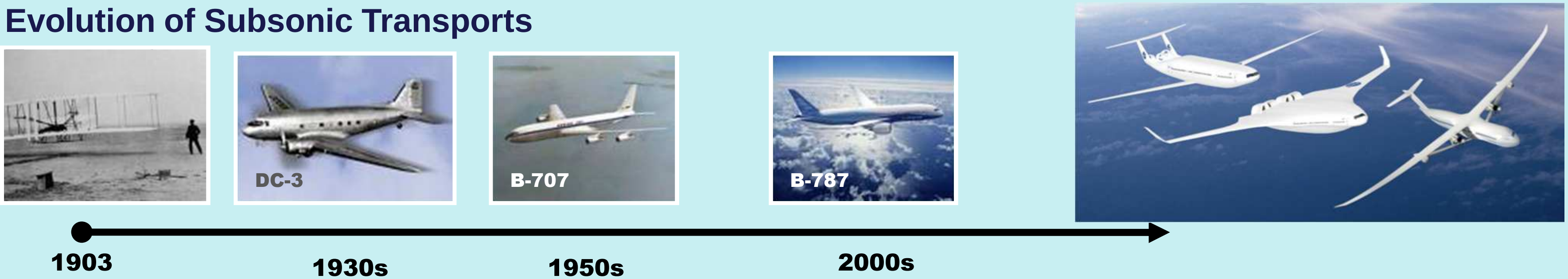
Vision

- Early-stage exploration and initial development of game-changing technology and concepts for fixed wing vehicles and propulsion systems

Scope

- Subsonic commercial transport vehicles (passengers, cargo, dual-use military)
- Technologies and concepts to improve vehicle and propulsion system energy efficiency and environmental compatibility
- Development of tools as enablers for specific technologies and concepts

Evolution of Subsonic Transports



Fixed Wing Project Organization Chart

PROJECT LEVEL

Rubén Del Rosario, Project Manager
John Koudelka, Deputy Project Manager
Richard Wahls, Project Scientist
Nateri Madavan, Deputy Project Scientist
Kimlan Pham, NRA Manager
Susan Crawford, Business Lead – Amanda Eberwine, Scheduler

Michael Rogers, ARC DPMf
Sandra Ramirez, Analyst

Gary Martin, DFRC DPMf
Rebecca Miani, Analyst

James Walker, GRC DPMf
Susan Crawford, Analyst

Susan Wilz, LaRC DPMf
Susan Price, Analyst

System Analysis & Integration
William Haller, TL
Mark Guynn, ATL

ACCESS Alt Fuel Flight Experiment
Brian Beaton, TIM

SUBPROJECT LEVEL

Aerodynamic Efficiency
Scott Anders, TL
Nhan Nguyen, ATL

- Higher Aspect Ratio Optimal Wing
- Quieter Low-Speed Performance
- Unconventional PAI

ARC, *LaRC*

Structural Efficiency
Karen Taminger, TL

- Lighter-Weight, Lower-Drag Fuselage
- Higher Aspect Ratio Optimal Wing

DFRC, *LaRC*

Propulsion Efficiency
Michael Hathaway, TL

- Cleaner, Compact, Higher BPR Propulsion
- Hybrid Gas-Electric Propulsion
- Unconventional PAI

ARC, DFRC, *GRC*

Quiet Performance
Chris Miller, TL
Douglas Nark, ATL

- Quieter Low-Speed Performance
- Cleaner, Compact, Higher BPR Propulsion
- Unconventional PAI

ARC, *GRC*, LaRC

Clean Power
Dan Bulzan, TL

- Cleaner, Compact, Higher BPR Propulsion
- Alternative Fuels

DFRC, *GRC*, LaRC

Note: The home center of each tech lead (TL) is in italics.

N+3 Advanced Vehicle Concept Studies

Summary

Boeing, GE, GA Tech

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 Entry into Service (EIS)

Trends:

- Tailored/Multifunctional Structures
- High AR/Laminar/Active Structural Control
- Highly Integrated Propulsion Systems
- Ultra-high BPR (20+ with small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

NG, RR, Tufts, Sensis, Spirit

GE, Cessna, GA Tech

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

NASA

Advances required on multiple fronts…

Fixed Wing Portfolio Addressing N+3 Goals

broadly applicable subsystems and enabling technologies

Goals *Metrics (N+3)*	*Noise* *Chapter4 **-52** dB cum*	*Emissions (LTO)* *CAEP6 – 80%*	*Emissions (cruise)* *2005 best – 80%*	*Energy Consumption* *2005 best – 60%*

N+3 Vehicle Concepts

Research Themes	**Lighter-Weight Lower-Drag Fuselage**	**Higher Aspect Ratio Optimal Wing**	**Quieter Low-Speed Performance**	**Cleaner, Compact, Higher BPR Propulsion**		**Hybrid Gas-Electric Propulsion**	**Unconventional Propulsion-Airframe Integration**	**Alternative Fuels**
Technical Challenges	**Fuselage Structural Weight -15%**	**Optimal Aspect Ratio +50 to 100%**	**Community Noise -12 dB, Cum**	**Low NOx Fuel-Flex Combustor CAEP6 -80%**	**Compact High OPR (50+) Gas Generator**	**Elec. Motor Power Density +100%**	**Integrated Boundary Layer Ingestion System**	**Alternative Fuel Emissions at Cruise**
Technical Areas	Tailored Load Path Structure	Aerodynamic Shaping Adaptive Aeroelastic Shape Control Tailored Load Path Structure Designer Materials Active Structural Control	Active Flow Control Airframe Noise Acoustic Liners & Duct Propagation	Fuel-Flexible Combustion	Hot Section Materials Tip/Endwall Aerodynamics	Electric System Materials Electric Components	Aerodynamic Configuration BLI Inlet/Distortion Tolerant Fan Propulsion Airframe Aeroacoustics	Emissions & Performance
	Designer Materials			Core Noise		Power Management & Distribution	Adaptive Fan Blade	Fuel Properties

Aero

Struc

Prop

Clean

Quiet

Note: Items below dashed line are other research theme investments (ORTI)

Quiet Performance Content Outline

- **TC3.1 - Community Noise**
  - Airframe Noise
  - Acoustic Liners and Duct Propagation
- **TC4.1 - Low NOx Fuel-Flex Combustor Active Flow Control**
  - Core Noise
- **TC6.1 - Integrated Boundary Layer Ingestion System**
  - Propulsion Airframe Aeroacoustics

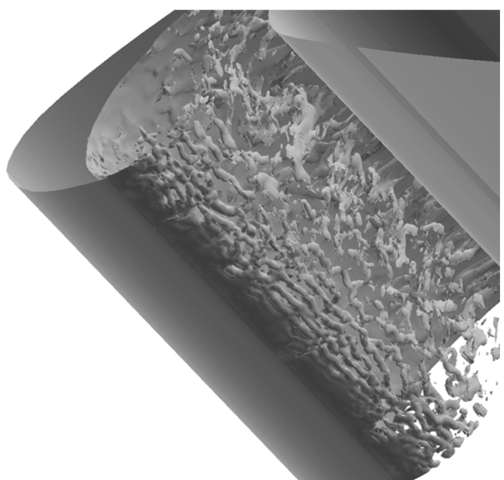
Quiet Performance (QP) 2Q FY13
TC3.1: Community Noise -12 dB, Cum

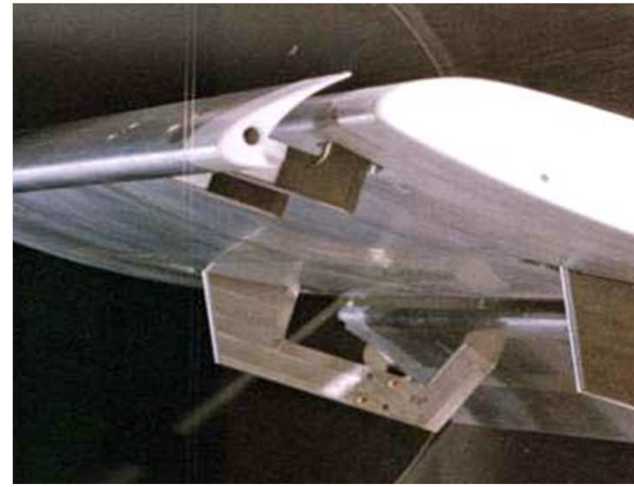
Technical Approaches

- Airframe Noise: Flap, slat, & landing gear noise reduction
- Acoustic Liners & Duct Propagation: Advanced liner configurations, low-drag liners

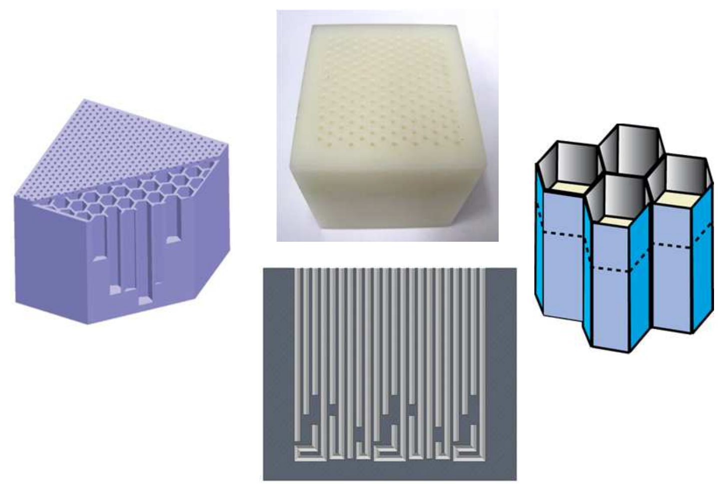
FY13 Milestone

- FW.2.A.07.03.004, “AMELIA Acoustic Low Speed Config Benchmark,” L2 ARC, 9/30/2013





Multi-Degree-of-Freedom Liner Concepts



Quiet Performance (QP) 2Q FY13
TC3.1: Community Noise -12 dB, Cum

- Novel Materials
  - Elastomeric materials identified for FLEXsel application (M. Lebron-Colon)
  - Slat-Cove/-Gap Fillers (SCF,SGF): Monolithic superelastic shape memory alloy (SMA) & shape memory polymer composite (SMPC) bench-top hardware developed and under test. (T. Turner)
  - Developed optimization schemes for SMA/SCF, & collected approaches for computational simulation of elastomeric structures.
- Flap / Slat systems
  - G550 test of Flexible Side Edge Link (FLEXsel) candidates in 14x22 showing promising performance was obtained. (M. Khorrami, T. Turner)
  - Boeing/Florida State University test report on 30P30N high-lift system delivered & under study for discrepancies with NASA computations.
- Landing Gear
  - Automated field grid refinement successful; needs surface refinement. (V. Vatsa)
- Models for active flow control
  - AMELIA CESTOL data analysis underway. (C. Horne)

QP: Slat Cove Filler Via Variable Stiffness Polymer Composites (LaRC VSPc)

PROBLEM
- Aeroacoustic noise produced by the unsteady aerodynamic flow around high-lift devices is sufficient to limit the expansion of airports. Filling the slat cove is one approach that has been shown computationally and experimentally to reduce this type of noise. The challenge in designing a slat cove filler (SCF) is to produce a highly-reconfigurable structure that can sustain the aerodynamic load.

OBJECTIVE
- Develop novel variable-stiffness materials to create an active slat cove filler to reduce airframe noise.

APPROACH
- Fabricate durable composite by laminating newly developed LaRC variable stiffness polymer composite (LaRC VSPc) with superelastic shape memory alloy sheet (SMA, NiTi alloy).
- Fabricate bench-top models for concept demonstration of slat cove filler (SFC) designs.

RESULTS
Technical Progress:
- Development of a segmented electrode on bench-top model to enable spatial addressability of SCF. (Fig. 1)
- Fabrication-process optimization producing ¾" inch thick LaRC VSPc via molding for post-machining to precise SCF contour. (Fig 2).

Publications:
- Turner, T., "Structural Aspects of Airframe Noise Simulators," *Acoustic Technical Working Group Meeting,* 23-25 Oct. 2012, NASA LaRC, Hampton, VA

SIGNIFICANCE
- Successful demonstration of selective activation of LaRC VSPc SCF illustrates feasibility of deployment/retraction optimization for minimum load and may also benefit the flex-skin task in the FW project.

Team Members:
- Jin Ho Kang (NIA), Ron Penner (STC), Travis Turner, Mia Siochi

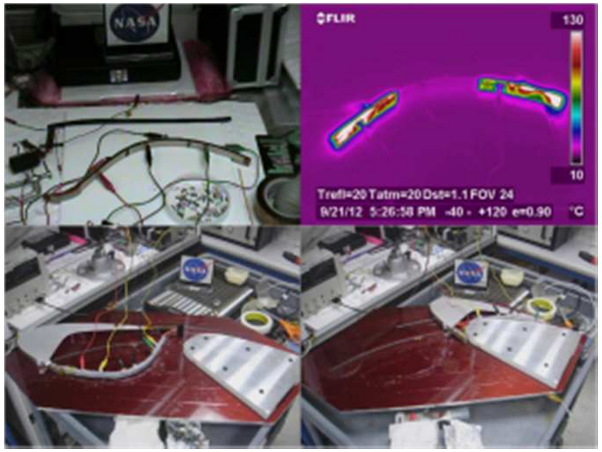


Fig. 1. Selective activation with segmented electrodes and bench-top model demonstration.

Fig. 2. ¾" thick LaRC VSPc block for precise machining.

Quiet Performance (QP) 2Q FY13
TC3.1: Community Noise -12 dB, Cum

- Metamaterials (non-linear acoustic behavior)
  - Literature search for liner applications
  - Initial COMSOL modeling completed; initial validation model under construction for Normal Incidence Tube (NIT) test. (B. Beck)
- Liner drag measurement
  - LaRC MEMS chips being packaged for CDTR evaluation (M. Scott, E. Adcock)
  - Univ Florida NRA MEMS packaging and tunnel instrumentation progressing. Test will obtain shear stress, LDV data, PIV data. (See Fall 2012 TWG; C. Gerhold).
- Curved Duct Test Rig (CDTR)
  - Liner surface roughness: test articles to be rapid prototyped (B. Howerton)
- Duct Analyses
  - Software validated for CDTR asymmetric tests & implementation of simultaneous eduction techniques (analysis efficiency) (C. Gerhold, M. Jones)
- MDOF static liners
  - In-house analysis & design with Hexcel, for test on the ANCF. (M. Jones, D. Nark, D. Sutliff)

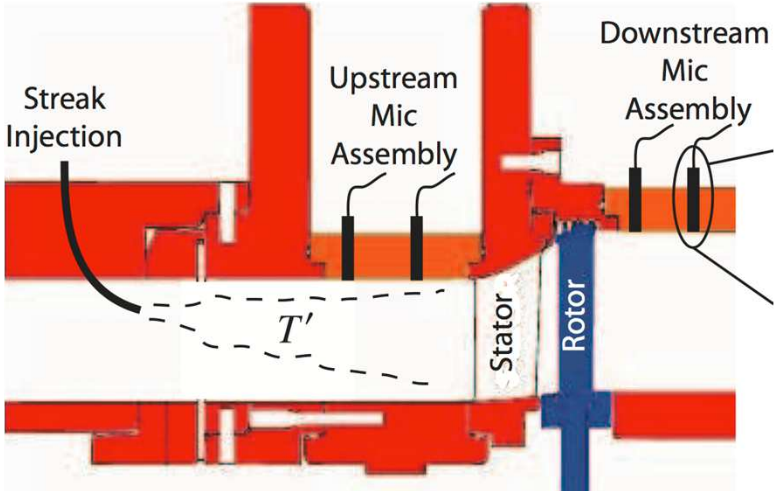
Quiet Performance (QP) 2Q FY13
TC4.1: Low NOx Fuel-Flex Combustor CAEP6 -80%

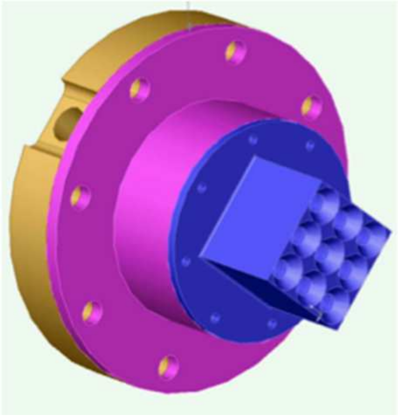
Technical Approaches

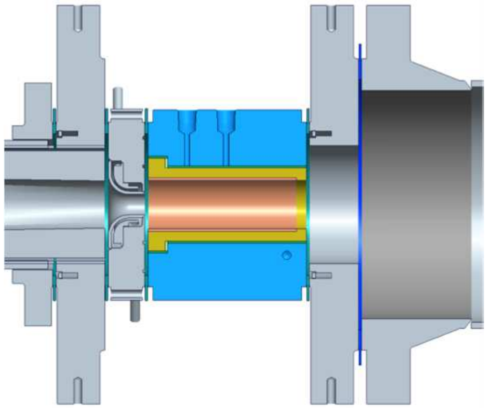
- **Core Noise**: Understand N+3 fuel-flexible combustor noise physics/challenge

FY13 Milestones

- FW.2.L.07.04.001, “N+3 Noise Goal,” L2 LaRC 10/31/2012, **Completed**
- FW.3.G.07.04.003, “LDI Combustor Rig Assessed for Noise Data Quality,” L3 GRC 9/30/2013, **On Track**





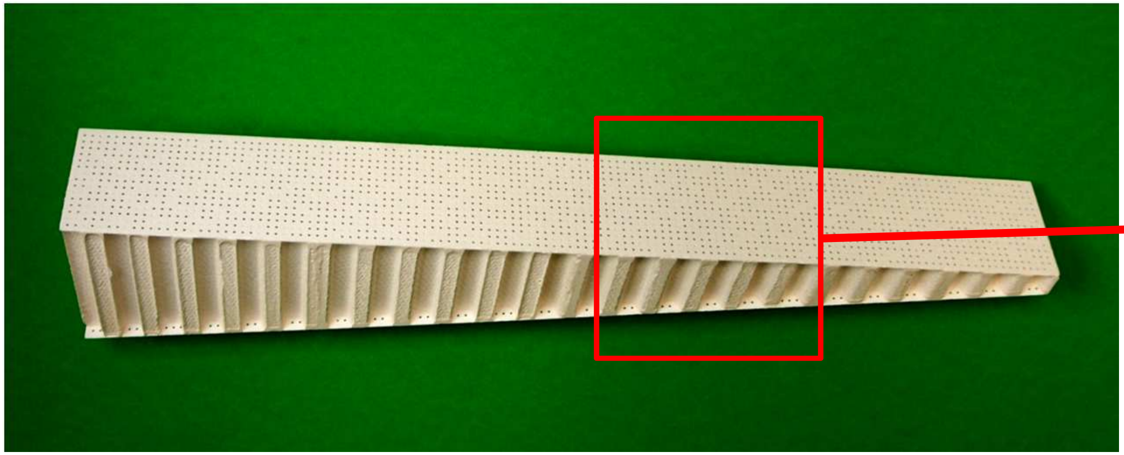


(Left) GRC lean, premix, nine-point fuel injector.
(Right) Downstream acoustic measurement section.

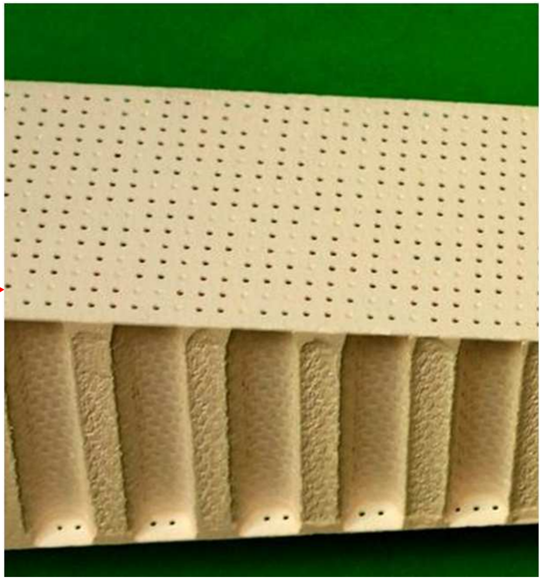
Honeywell TECH977 Turbofan in Test Cell

Quiet Performance (QP) 2Q FY13
TC4.1: Low NOx Fuel-Flex Combustor CAEP6 -80%

- Lean Direct Injection (LDI) combustor testing
  - Instrumented spool piece for late summer test progressing (L. Hultgren)
- NRA with Honeywell
  - Unsteady turbine P & T from instrumented TECH977 engine test soon. (L. Hultgren)
- NRA with U. of Illinois Urbana-Champaign/U. Notre Dame
  - UICU LES computations on UND turbine stage progressing.
- Acoustic liner application to core noise
  - CMC honeycomb (D. Kiser) NIT & GFIT tests (M. Jones) completed. Data analysis underway.



CMC Test article for Grazing Flow Impedance Tube (GFIT)

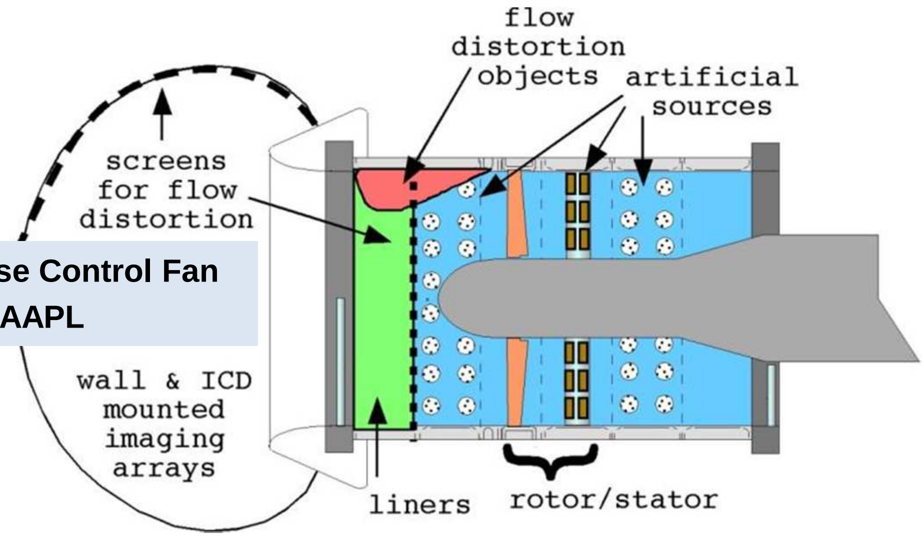


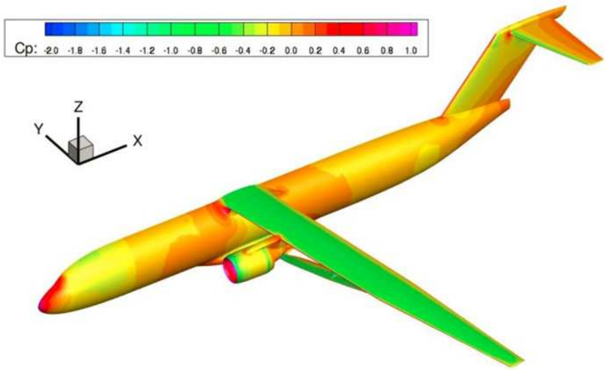
Quiet Performance (QP) 2Q FY13
TC6.1: Integrated Boundary Layer Ingestion System

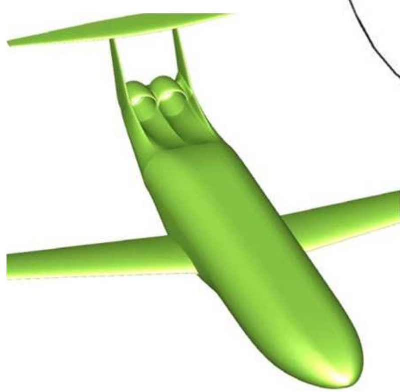
Technical Approaches

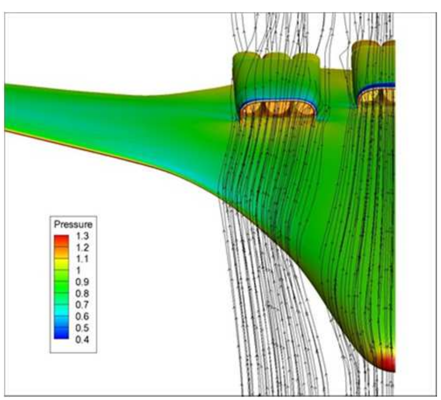
- Propulsion Airframe Aeroacoustics: Installation Effects, Inlet Distortion, Short Duct Inlet Aeroacoustics

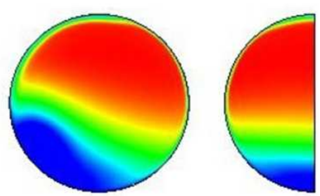
Advanced Noise Control Fan
ANCF @ GRC/AAPL



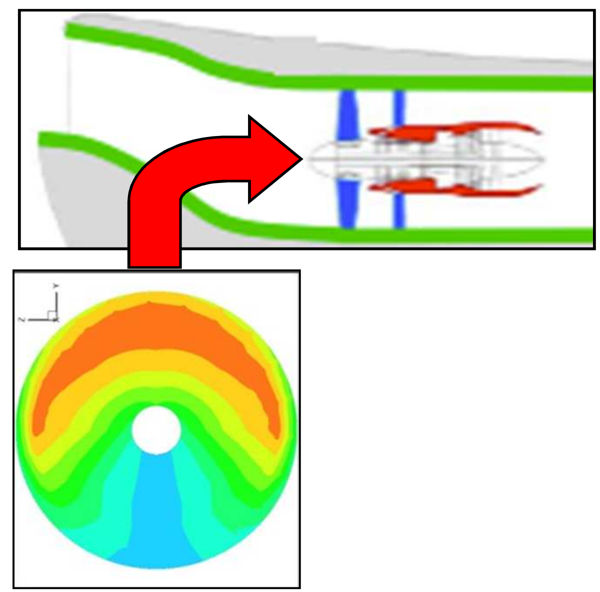








Distortion in center engine paths



Quiet Performance (QP) 2Q FY13
TC6.1: Integrated Boundary Layer Ingestion System

- Inflow distortion noise associated with the embedded or short duct podded engines of N+3 concept vehicles
  - Analytical model for response to distortion (D. Koch)
  - Evaluating FINE/Turbo™ for open rotor pylon distortion (E. Envia)
- Assess and enhance current computational tools for concept evaluation
  - Evaluating aero (e.g. FINE/Turbo™, FUN3D) and acoustic (e.g. LINPROP, QPROP, ASSPIN, F1A). (E. Envia, D. Nark)
- Use historical and current ducted and un-ducted fan noise data to extend low-order models for use in ANOPP2
- Evaluate acoustic scattering codes and generation of low-order scattering models via ERA LSAF & 14x22 HWB tests
  - 14x22 Hybrid-Wing Body data acquired and analysis underway. (T. Brooks)
- Exhaust Noise
  - Analytical modeling, non-round jets & jet-trailing edge. (Leib; Afsar & Goldstein)
  - Model for entropy term in hot jets developed and implemented. (A. Khavaran)
  - Planning for the upcoming JSIT3 test. (C. Brown)

Exhaust Noise
Dual Stream Jets

PROBLEM

Turbulent mixing noise is an integral part of jet engine noise under high thrust conditions and the prediction of noise due to thermal variations has been lacking. The thermal source strength in heated jets is associated with the variance in stagnation temperature. Normally a dedicated flow solver with an enthalpy-variance and dissipation-rate model is needed to evaluate the source strength.

OBJECTIVE

Develop an empirical temperature variance model for the heat-related entropy source strength that can be used with standard RANS solvers (such as Wind-US), to evaluate the missing terms from the mean flow and turbulence.

APPROACH

An empirical temperature variance source model is now implemented within the acoustic analogy noise code JeNo that predicts exhaust noise in axisymmetric heated jets, and can handle turbulent mixing noise in jets with an inverted velocity and/or inverted temperature profile.

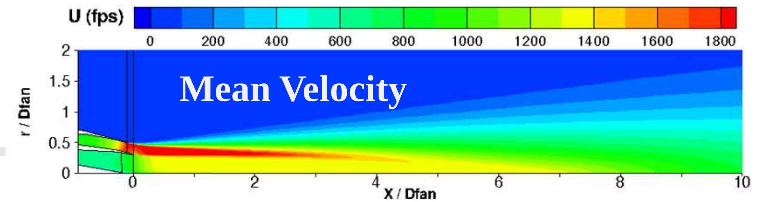
RESULTS

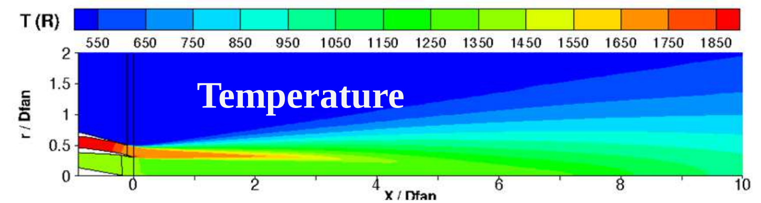
The dual stream jet considered here operates with an inverted velocity profile (Ufan/Ucore=1.39) and inverted temperature profile (Tfan/Tcore=1.31). The RANS solution (Wind-US) for mean velocity and static temperature are shown in the contour plots. Two major exhaust noise sources, associated with the turbulent kinetic energy, $TKE^{0.5}/Uj$, and variance in stagnation temperature,
$S(dT_t /dr)$, are also shown. A sample jet noise spectrum at 120° from nozzle inlet shows good agreement with data to within 2dB. Overall, the prediction accuracy is similar to that for unheated jets.

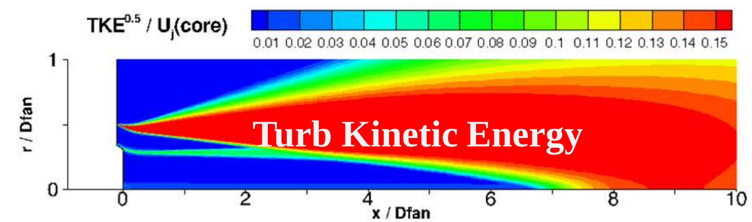
SIGNIFICANCE

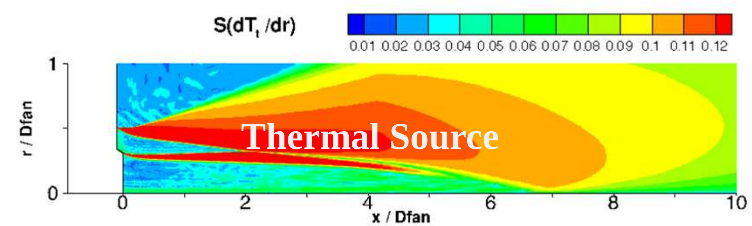
A model has been implemented for the entropy-related source in hot jets. The source strength is easily evaluated using commonly available RANS solvers, and the resulting accuracy is sufficient for design and analysis in axisymmetric jets.

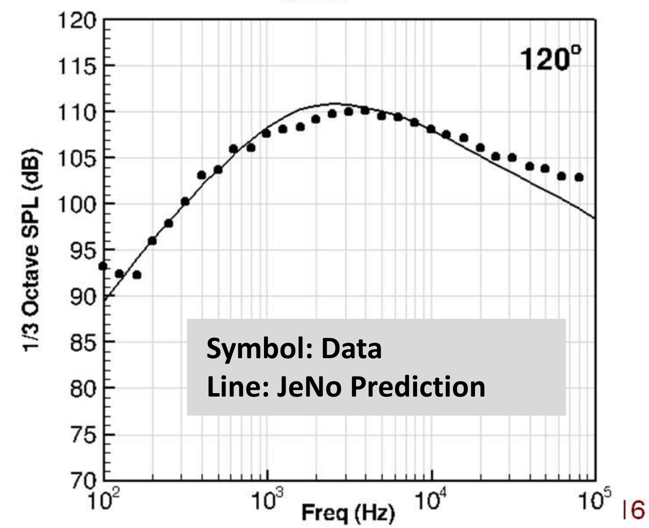
Researcher: Abbas Khavaran, (Vantage Partners/GRC)











Quiet Performance (QP) 2Q FY13
Other Research Theme Investment

- Development and validation of small (8" diameter) microphone arrays for in-flow measurements in large scale facilities (NFAC)
  - To be evaluated during upcoming NFAC test. (C. Horne)

- Open rotor data processing is complete and data is available.
  - Analysis of the data continues. (D. Stephens, G. Podboy, H. Vold)

- Rotating rake analysis extended to sheared flows.
  - Validation experiment underway. (M. Dahl, D. Sutliff)
  - CAA validation. (R. Hixon)

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